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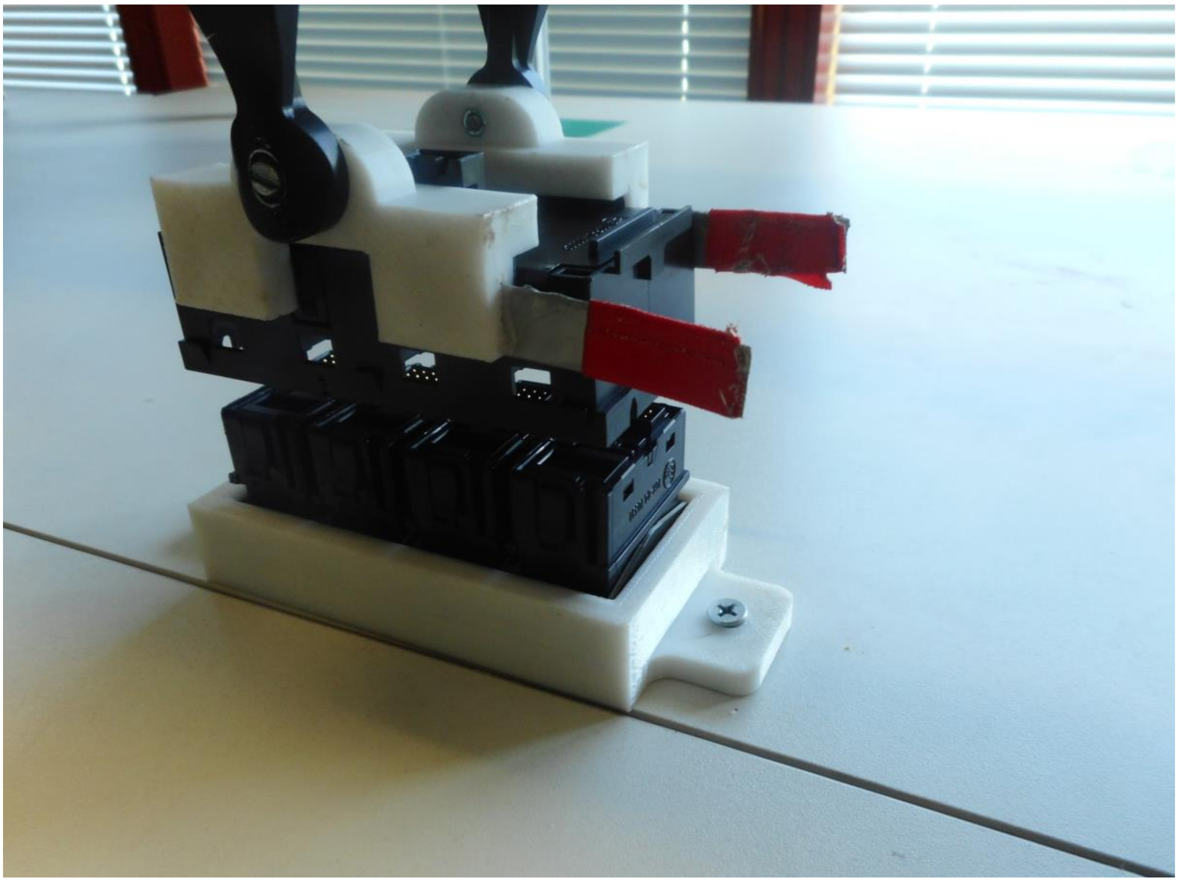

Robotic Assembly of Switches

Thesis work within Mechatronics

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Gothenburg, Sweden 2018

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Bachelor Thesis Work 15 ECTS

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Abstract

Increasing the level of automation comes with several benefits such as improved product quality and making the tasks for the operators less strenuous. Moreover, it is a prerequisite for the transformation to Industry 4.0, the manufacturing technologies of tomorrow.

The main task of the project was to investigate whether or not the assembly of switches for the truck interior is a suitable process to automate with a collaborative robot. Other parts of the project included designing and 3D-printing tools for the robot, building a material rack for the switches and connectors and the use of an AGC to link the operator side of the station to the robot area.

It was discovered at an early stage that the robot that had been put at our disposal lacked the necessary safety features to be considered a collaborative robot. A more traditional solution, with the operator and the robot separated from each other had to be implemented. Nevertheless, the implemented non-collaborative solution serves as a showcase for robotic assembly of switches and it can be concluded that the use of robots for this task is both feasible and fruitful.

NB: pictures of the robot have been censored due to non-disclosure agreements.

Search words (Swedish): lastbil, kollaborativ, programmering, industri 4.0, montering, montör, ergonomi, 3D-skrivare, fordonsindustri, fabrik, algoritm

Foreword

The project leading up to this thesis work of 15 ECTS took place between January and June 2018 in cooperation with Volvo Group Trucks Operations, at the plant located in Tuve, Gothenburg. As mechatronics students at Chalmers University of Technology, we already had a basic understanding of automation technologies but a project of this size and degree of complexity was a first for us. However, thanks to the experience we now have gained, it was most certainly not the last.

We would like to extend our gratitude to the company for having shown confidence in us and letting us conduct our thesis work in their excellent facility Pilot Plant. Mikael Granbom, Per-Anders Alveflo and Per-Anders Torén also deserve special thanks for their constant support and good advices along the way.

We hope that You will enjoy this report!

Simon Johansson and Isak Abrahamsson

Wordlist

AGC - Automated Guided Cart

FH/FM - Two of the truck models made in the Tuve plant

HMI-panel - The Human Machine Interface panel. It is located on the center stack of the dashboard, next to the driver.

Inboard/Outboard panels - Two smaller panels located on each side of the steering column in the truck's dashboard.

SID/CP - The radio and climate control panels. They are both attached to the HMI-panel.

Switchcalc - Volvo's IT-system for creating switch layouts in the truck interior.

ABB Robot Studio - Software from ABB to program and simulate robots

TCP - Tool Center Point, the user-defined center point of the robot tool

QULIS - Volvo's IT-system for logging errors in production

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1. Introduction

A collaborative industrial robot, unlike a conventional industrial robot, is designed to work side by side with a human without any safety cage or other shielding surrounding it. This arrangement makes it possible to automate tasks, which previously have been regarded as too difficult and costly to automate. Ideally, the collaborative robot relieves the employees from monotonous tasks while at the same time increasing productivity and quality [1].

1.1 Background

At Volvo Group Trucks Operations each truck is built entirely after the customer's specification. Because of the wide variety of options and equipment that can be ordered by the customer, the assembly of switches for the truck's dashboard is a highly varying task.

Today, the assembly is carried out entirely by hand after directives from a program called "Switchcalc", which keeps track of the switches required to fulfill the customer orders. The switches are of a standard format and are placed in connectors, each holding four switches, that in turn connects to the truck's data bus system. This means that the applications of the switches are assigned virtually, through programming, thus making their position important even though a data bus is used.

Due to the standardized format of the switches, it becomes possible for a human operator to fit the switches in the wrong position. When the dashboard is later programmed, misplaced switches won't have the intended function or won't function at all.

The international standard ISO/TS 15066:2016 that came out in 2016 contains vital information about the safety features required for collaborative robots. It will provide guidance during the design phase, as well as during the test phase and delivery of the complete work station to AB Volvo. To be considered as an alternative to today's manual assembly station, the collaborative work station needs to comply with ISO/TS 15066:2016 and other safety requirements.

1.2 Purpose

The purpose of the project is to build a collaborative work station in Volvo Trucks Pilot Plant in Tuve. The station should be capable of handling the entire production process for the HMI-, Inboard- and Outboard panels, which today is carried out by hand (see Appendix 4). Once operational, the collaborative work station will serve as a showcase for new technology and influence similar projects in the future.

Having a showcase facility at your disposal makes it possible to evaluate task allocations between humans and robots. Certain tasks may be too difficult for the robot to handle and therefore must remain manual, and vice versa.

Another purpose is to find out whether or not the assembly of switches and connectors is suitable to automate with a collaborative robot. The current manual assembly station is in this respect a benchmark for the collaborative station to be compared with. If it can be shown that the human-robot collaboration is safe and efficient, the solution may well be implemented in real production in the future.

1.3 Delimitations

The delimitations made in the execution of the project are explained and motivated here.

1.3.1 Scope

The project was entirely focused on the tasks carried out at the current station (see Appendix 4).

1.3.2 Time

The deadline for the thesis work was set to be before the factory summer break in mid July 2018. This limited the scope of the work, so that it could be completed within this timeframe. Therefore, the project concentrated on the FH-series and not the FM, and the switches located above the windscreen were left outside the scope.

1.3.3 Robot

The robot used in the project was already specified by Volvo. It was also decided that the robot should cooperate with either a worker or an AGC or both, depending on the safety features of the robot.

1.3.4 Product design and variants

The project focused exclusively on left hand drive FH-series trucks.

The interior of the FH-series truck contains several panels, but the large main panel situated in the middle of the dashboard (the so called "HMI-panel") was decided to be the priority task of the project. The HMI-panel is the hardest to assemble and requires an operator to execute some of the steps. One can assume that if the robot-operator collaboration is successful when assembling this complex part, then a similar solution can be applied on the assembly of the smaller and simpler panels, such as the Inboard- and Outboard panels.

Furthermore, there are at least 160 types of switches available. Developing a system that can keep track of and assemble such a wide variety of switches would be an overwhelming task with the given time frame. Instead, a more limited selection of switches was used.

The design of the switches and connectors will not change following the automation of their assembly. As won't the containers and the protective cardboard or foam surrounding the parts upon delivery to the factory. The design of the truck's dashboard and interior will also remain unchanged during the project.

1.3.5 Auxiliary systems

Volvo's own program to generate assembly layouts for the switches, Switchcalc, can unfortunately not be used in the project due to software compatibility reasons. The output-data from Switchcalc is just a static picture of the switch layout, hence it cannot be used as in-data for the robot system.

Instead of using Switchcalc data, a local system will be created for the work station to simulate the real production environment. Reworking the Switchcalc software so that it can be linked to a robot could be a task for another thesis work.

1.3.6 Operator area and AGC

Another large part of the work is to design the operator work station, but due to the limits in time that responsibility is handed over to another group. This includes worker ergonomics and designing the AGC system with all its aspects. For further details about the operator's tasks, we suggest reading the thesis produced by Ingrid Larsson and Johanna Karlqvist about the operator and AGC parts of the project [2].

1.4 Clarification of questions

The main question of the project:

- Is the assembly of switches for the truck's dashboard a suitable task to automate?

Designing the robot work station also includes the following aspects:

- **Layout.** This includes how the switches and connectors are delivered to the robot and how they are transported away.

- **Tools and fixtures.** The standard gripper may have to be replaced by a customized one, if it is not suitable for the process. Fixtures for the assembly have to be designed and manufactured.

- **Programming.** The robot is to be programmed to perform its tasks in a safe and efficient way.

- **Safety features.** For commercial implementation the international standard ISO/TS 15066:2016 for collaborative robot safety has to be fulfilled. However, the Pilot Plant of the Volvo Tuve factory counts as a "laboratory environment", meaning less strict safety demands than those stipulated in ISO/TS 15066:2016.

- **Communication with IT systems.** Information of where which switch will go has to be communicated to the robot in some way.

- **Communication between robot and operator.** The operator and robot have to communicate with each other through some type of interface.

2. Theoretical frame of references

This chapter provides a general overview of collaborative robots and their application.

2.1 Collaborative robots

The term "collaborative" in the context of robots means a robot capable of working alongside an operator without being separated by a fence, while power to the robot's actuators is available [3]. However, this widely spread definition is not the whole truth. The fact is that practically any robot can be made safe enough for collaborative operation if you just add the right set of sensors, capable of detecting human interference, to the existing hardware and proceed to program it in a way that conforms to the international standards [4].

Having said that, there are collaborative robots, whose collaborative capabilities don't rely on external sensor arrangements. These robots are referred to as power and force limited, meaning that they have built-in sensors in their joints capable of detecting abnormal forces. An overload in force is interpreted as a possible accident and the robot will stop automatically. This type of robot is also designed with round edges and sometimes a soft skin on the outside, to distribute and cushion collision forces [4].

While conventional industrial robots have been around since the 1970's, improving speed and efficiency in production a great deal, very few collaborative robots have made it to the factory floors. With recent advances in technology, this is about to change. Europe's two leading manufacturers of robots, ABB and KUKA, both offer collaborative robots and the world market is predicted to grow to $ 1 billion by the year 2020 [5].

2.1.1 Collaborative robot operation and safety

As is the case with many technical systems, the safety features of a collaborative robot can be categorized as either active or passive. Passive safety is about minimizing the damage whenever an accident occurs, while active safety should prevent the accident from happening in the first place.

Generally, the passive safety features are incorporated in the mechanical design of the robot. As mentioned in section 2.1, such features include rounded edges (with a minimum radius of 10 mm) and covering the moving parts with a soft skin to distribute collision forces. Another possibility is to make the hazardous parts compliant and/or deformable. It could be viewed as building in strategic weaknesses in the robot that can serve as an extra layer of safety when an accident occurs. For example, a robot arm that is weak enough to be pushed away by an average human's hand force poses less of a risk than a stronger and sturdier one in the event of a collision [3].

The active safety is a part of the robot's control design and is different depending on what type of collaborative operation is being performed. The ISO/TS 15066:2016 lists four methods for collaborative operations. Collaborative operation may include one or more of these four methods:

a) **Safety-rated monitored stop**
The robot motion is stopped prior to operator interaction within the collaborative workspace. Once the operator has left the collaborative workspace, the robot can resume its motion and may operate non-collaboratively (like a conventional industrial robot).

b) **Hand guiding**
The operator uses a hand-operated device to guide the robot. Upon entering the collaborative workspace, a safety-rated monitored stop shall be activated and cleared as the operator begins to use the hand-operated device. The robot shall also stop if the operator lets go of the device.

c) **Speed and separation monitoring**
A protective separation distance is programmed. The robot and operator are allowed to work alongside each other within the collaborative workspace as long as the distance is held. If the robot comes too close to the operator, it stops. It automatically starts again when the distance exceeds the programmed minimum value. Alternatively, the robot may avoid violating the separation distance by reducing its speed or executing a different path further away from the operator.

d) **Power and force limiting**
The robot utilizes built-in sensors to monitor physical contact between the robot and the operator. Threshold limits for power and force are programmed to protect the operator from getting hurt in the event of a collision or clamping situation. The operator shall be able to easily escape a clamping situation.

2.1.2 Types of interaction

There are five types of interaction between humans and robots [6], as displayed in Figure 1.

- **Cell** - The robot is surrounded by a cage. No interaction takes place.
- **Coexistence** - The human and robot are separated by distance. The robot has no cage surrounding it.
- **Synchronized** - The human and robot share workspace and workpiece but perform their work at different times.
- **Cooperation** - The human and robot perform work simultaneously but on different workpieces.
- **Collaboration** - The human and robot share workpiece, workspace and perform their respective tasks simultaneously.

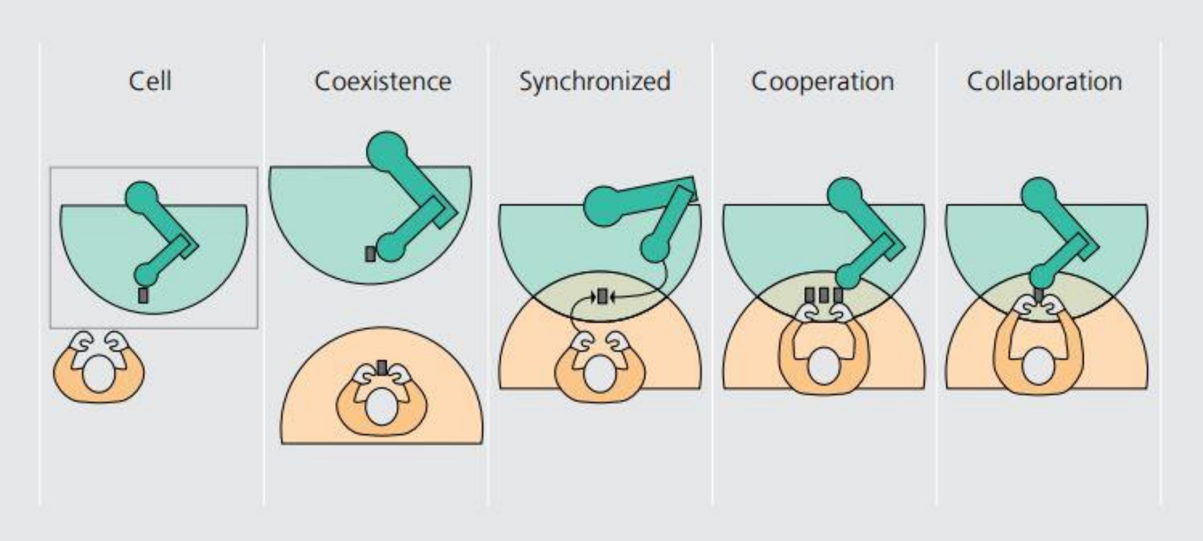

Figure 1. Types of human-robot interaction. From [6]. Reproduced with permission.

2.2 Industry 4.0

Industry 4.0 is a buzzword in future-orientated businesses such as the automotive industry. It is defined as self-organizing production with a very high level of information exchange between equipment within the factory and the outside world, i.e. R & D facilities, suppliers, maintenance personnel etc. The result is a boost in efficiency, reduced downtime and a better overview of the process from a management point of view, which helps to increase overall competitiveness. Another benefit is the increased ability to cater for smaller, “tailor-made” customer orders, since the production facility adapts faster and in a more economical way [7].

Implementation of Industry 4.0 can be broken down into six steps, the so called “value-based development stages” [8].

1. **Computerization**.
2. **Connectivity**.

Computerization and connectivity are two basic conditions that have to be satisfied before the transformation to Industry 4.0 can begin. Without a fully built-out computer network spanning across the entire process, from the design department to the machines on the workshop floor, full automation is impossible to achieve.

Once these basic conditions have been met, the last four value-based development stages contain guiding principles on how to reach full implementation of Industry 4.0. The steps are building on each other meaning that, for example, the features stipulated in stage 5 can’t be implemented if the current development level corresponds to stage 3.

3. **Visibility**. By collecting data from sensors mounted on various places in the process, it is possible to create a digital shadow of the actual plant. The primary purpose of the digital shadow is to assist in decision making, by continuously feeding real-time data to the plant management.

4. **Transparency**. The collected data needs to be interpreted correctly if it is going to be useful. This is especially important when it comes to preventive maintenance, where a certain combination of parameters can indicate if a machine is nearing a break-down.

5. **Predictive capacity**. Using the information obtained in stage three and four, the system makes predictions of the future. The different future scenarios are then ranked depending on their probability of occurrence. This further assist decision making by the management and limits the negative impact of for example a machine failure, since the problem can be solved at an early stage.

6. **Adaptability**. The technology automatically adapts to changes in the business environment. It is for example able to make the decision to postpone the manufacturing of an order, based on information (obtained from the digital shadow) of an expected machine failure.

2.3 The DYNAMO++ method

At Chalmers University of Technology, a comprehensive method for automation analysis called DYNAMO++ has been developed since the early 2000's. The purpose of the method is to create an overview of the current state in a production process and identify the potential improvements in automation that can be made. Use of the method will not result in any specific automation solution, but it will point out the optimal *level* of automation for the analyzed process [9]. With the help of this indication, better decisions can be made when designing the future process. Due to the complexity of the method, only Level of Automation (LoA) will be used in the project. The purpose of LoA is to break down a given process into smaller parts, which can be further analyzed and given a physical and cognitive score depending on the level of automation.

A low score in the cognitive part indicates that the task is easier to control, while a lower physical score shows that the tools used can be less complex.

3. Methods

Our supervisor Mikael Granbom decided that the scope of the project would include the process taking place from the arrival of material (i.e switches, cables, plastic details and so on) to the station, to the complete panel ready to fit on the dashboard. This process constituted a “black box”, which was to be filled with a suitable solution. In order to find the best possible solution when dealing with this type of loosely defined task one has to work systematically, eliminating solutions that are not up to scratch. Each project phase and the methods employed will be explained here.

3.1 Current state analysis

The current work station was observed and analyzed. The purpose was to find out in detail, how to assemble the switches and dashboard and also how the truck’s switch specification is presented to the worker performing the assembly.

The switches are tightly fitted to the connector to ensure good conductivity and a quality feel when operating the switch. To ensure a correct fit, the connector is provided with guide pins that slide into corresponding slots in the switch. There is only one way of fitting the switch and the guide pins must match the slots exactly, as there is very little play between the parts. Switches and connectors are shown in Figure 2.

Figure 2. Switches and connectors.

A fixture is used to hold the HMI-panel in place while assembling the prepared connectors and installing the wiring loom. The fixture is turnable, as some parts are installed from the front side (facing the driver) of the panel while others are installed from the back side. However, no fixture is used when pushing the switches into the connectors. Instead, the operator gently places the switches on the right spot in the connector and then firmly pushes them in with the palm of his hand. The switches are delivered in a vehicle-specific kit (picked by another worker) and the operator has to sort them out first, as seen in Figure 2, before the assembly can begin.

A typical work cycle was filmed and personnel with experience of the station were interviewed to gain an insight in the problems they encounter when doing their work (see Appendix 1 for the interview).

Based on this information, several areas with improvement potential were identified:

- Pushing the switches into the connectors is a tiresome task. It requires a great deal of force and it is hard to see if the switch really has snapped in place.

- The switches picked from the shelves are poured out on the assembly table in a big mess, which then has to be sorted by the person assembling the panel (see Figure 2 and SOB for switch assembly, Appendix 4). This is a non-value adding operation and steals time from building the panel.

- Handling the packaging material leads to a lot of walking back and forth along the material shelves. You have to open new boxes and throw away the cardboard mesh surrounding the switches on every layer in the boxes.

3.2 Level of Automation

In order to determine a suitability automation level for the switch assembly process, a Level of Automation (LoA) analysis was performed. In the LoA analysis, both the physical and cognitive demands are taken into consideration and weighted together. The more steps of a task that are on a low physical level, the easier the process is to mechanize. The same holds true for the cognitive part; the lower level, the easier it is to computerize [9].

As shown in the LoA-matrix in Appendix 2, the assigned tasks are well suited for automation, since they score mostly in categories one and two in both the physical and cognitive categories.

3.3 Concept generation

A number of different concepts of how to design the collaborative station were generated together with the group responsible for the AGC-system. Concepts include layout, responsibility split and task allocation. The aim was to come up with new and different ways to organize and perform the assembly, utilizing the full potential of the robot and liberating the human from the most monotonous tasks. Sketches of the concepts are presented in Appendix 3, description of function is found in the paragraphs below:

- **Concept 1:** The robot and operator work alongside each other on the same table. The table is divided into three zones; the operator’s zone (blue), the collaborative zone (yellow) and the robot’s zone (green). The robot picks switches from nearby material shelves and prepares the connectors in the green zone. The operator receives his material (SID-CP, cables, screws etc.) from the AGC in the blue zone. The complete panel is built in the yellow zone, where the robot would install the prepared connector-switch assemblies and the operator would install the SID-CP and connect the wiring loom. The AGC is used as a kitting cart to run material from storage to the station.

- **Concept 2:** The robot and the operator are separated from each other. Switches are prepared in the robot area while the operator install the SID-CP on the HMI-panel and secures it upside-down on a fixture, along with the outboard panel, on the AGC. The AGC then moves over to the robot area where the switches are installed. The AGC then moves back to the operator area to install the wiring loom.

- **Concept 3:** The assembly procedure would be identical to Concept 1. The difference is that the AGC is used to move portable shelves containing different types of switches. By having several smaller shelves that can be moved with the AGC, a "library" of switches covering all article numbers could be built up. The advantage of this concept is that the station is able to handle a wide variety of switches, unlike in concept 1 and 2 where the size of the shelf has to be limited to suit the reach of the robot, thus limiting the amount of switch types that the station can handle.

3.4 Selection

The generated concepts were analyzed in-depth in order to evaluate pros and cons in different areas. These areas were: safety, ergonomics, speed, quality and flexibility, weighted in named order. Safety is ranked highest, since it is the most important aspect in a working environment as well as a core value of AB Volvo. Ergonomics is also ranked high because of the issues related to the current station (see section 3.1). The time spent on each station is critical on an assembly line, so the concept process has to be quick enough to fit inside the current time limits. Time savings and quality improvements can also be translated to cost saving. Flexibility was ranked last, due to the fact that the amount of switch types is relatively constant, without too many changes from one year to another. The standardized format of the switches also means less need for flexibility in the assembly process. As shown in Figure 3, the Pugh matrix concludes that concept 2 is best suited for further development.

Station		**Current**	**Concept 1**	**Concept 2**	**Concept 3**
Category	**Weight**				
Safety	5	Reference	-	0	-
Ergonomics	4		+	+	+
Speed	3		+	+	+
Quality	2		+	+	+
Flexibility	1		-	-	0
Weighted sum					
+			9	9	9
0			0	1	0
-			6	1	5
Total score			3	8	4
Futher development?			No	Yes	No

Figure 3. Pugh-matrix for different design concepts.

3.5 Robot start-up

The robot used in the project is a prototype model from ABB not yet launched on the market. Its arm has a range of approximately 1 m when fully stretched. The lifting capacity is 5 kg without tools. The robot was delivered with a fully electric gripper tool with adjustable gripping force. Pictures of the robot are censored due to non-disclosure agreements.

According to the definition of collaborative robot, as stated in ISO/TS 15066:2016, the robot isn't collaborative. The main issue was the lack of force sensors in the joints of the robot. This meant that the control system for the robot had no way of sensing a collision with the operator or other objects, which significantly increases the crush hazard. ABB could not tell us why they had left out such a vital feature, while at the same time claiming the robot to be collaborative, but we suspect that it has to do with the fact that it is a prototype still in development.

Despite the lacking collaborative capabilities, the robot works well for conventional robot tasks. Its precision when assembling the switches and connectors is excellent and it is programmed in a relatively straight forward way.

3.6 Robot programming and simulation

There are several different ways to program the robot. In this project a combination of them was used to create a working program. The most basic is hand-guiding, which makes it easy to store coordinates by simply moving the robot to the desired positions. The coordinates are then transferred to ABB Robot Studio on a laptop where they can be organized and used by different commands. Control logic and communication with operator and AGC are also be managed in ABB Robot Studio.

Regardless of which programming method is used, the program code is created in the ABB Rapid language. The language combines traditional programming logic, such as while- and for-loops, with specific commands for robot applications. One of the most common instructions is the Move-instruction which is used to move the robot's TCP from one position to another. ABB distinguish between linear and joint movements, meaning that even if destination position is the same the robot's path will differ depending on which type of movement you program.

By beginning the Move-instruction with MoveL, a linear path is selected. The TCP will then move to the desired position in a straight line. This is sometimes inconvenient for the robot, as it has to reorient every joint to suit the straight path.

If the MoveJ instruction is used, the TCP will follow a non-linear path, which is quicker [10].

Example of Move-instruction:

MoveL p10, v1000, z50, tool0;

The example shows a linear movement to a position called p10 with the speed of 1000 mm/s. Z50 indicates a deviation tolerance of 50 mm from the position p10, a large tolerance enables the robot to move quicker and smoother while smaller tolerances are needed for precision work. Tool0 is what tool is being used (in this case no tool, just the tool mounting flange).

3.7 Tools and fixtures

Compared to the robot, the human is vastly superior when it comes to finding the “sweet spot” when the switch snaps into the connector. The robot lacks the touch and feel of the human and is reliant upon special tools and fixtures to get the job done.

A convenient way of making tools and fixtures is to use additive manufacturing, also called 3D-printing. The Pilot Plant of Volvo Trucks has a state-of-the-art 3D-printer capable of printing objects with a maximum base area of 380 by 380 mm. The printing material is a very hard and durable type of plastic, reminiscent of metal (it can even be threaded). To commence the printing, a CAD model is downloaded to the printer. In this project Catia v5 from Dassault Systemes was used for designing the tools and fixtures.

4. Results

This chapter contains the results and the knowledge AB Volvo gained from this thesis work.

4.1 Task allocation

A very strict separation between the robot and the operator has been implemented. No physical interaction at all takes place between the operator and the robot, instead they are linked together by the AGC.

The task allocation was made with safety, ergonomics and quality in mind. The robot will handle the preparation of switches, i.e. picking switches from the shelves, placing the switches in a connector and then insert the connector into the panel section delivered by the AGC. These are the most strenuous tasks, as well as the most critical ones from a product quality point of view. The problem with misplacement of switches is eliminated while the working environment for the operator is improved a great deal.

Placing and securing the SID-CP unit and connecting the wiring loom will be made by the operator in the operator area. The operator will also place the panel sections on the AGC and make sure that they are in their correct position before the robotic assembly sequence begins.

4.2 Station layout

The chosen layout is described by concept 2 (see section 3.3 and Appendix 3). This station does not constitute a collaborative station, something that we had to accept since the collaborative capabilities of the robot didn't live up to the ISO/TS 15066:2016 safety criteria. As mentioned in section 3.4 the robot lacks power and force sensors. Efforts were made to get additional equipment for the robot so that it could perform safety-rated monitored stops and/or speed and separation monitoring instead. This equipment was however not available at the manufacturer of the robot, ABB.

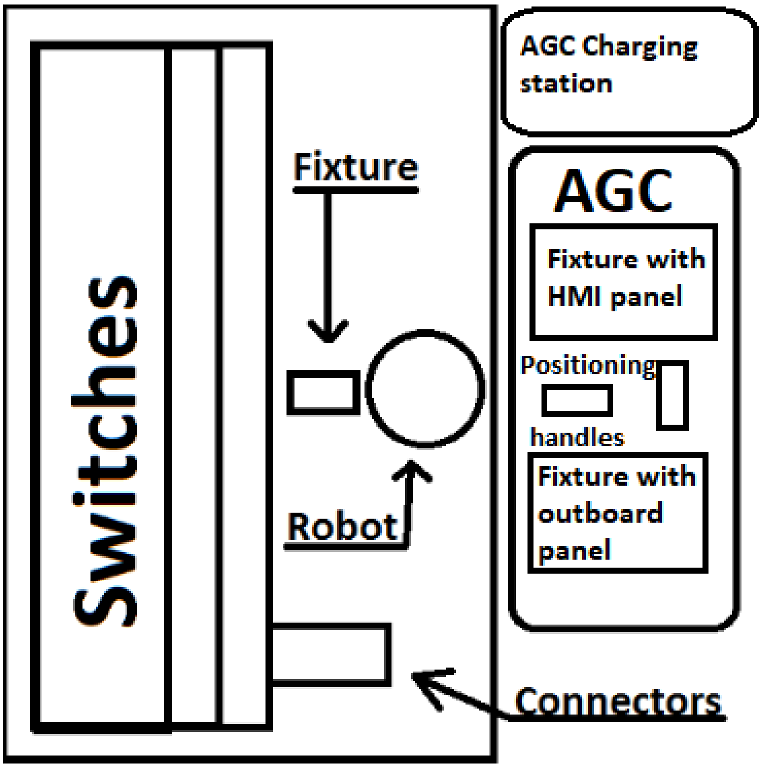

Figure 4. Robot area layout.

As described in Figure 4, the robot area contains the robot itself, storage shelves for boxes containing the switches, a chute for the connectors and a fixture to ensure that the switches are positioned perfectly for the assemble. The AGC loading area is located on the other side of the robot. The robot is mounted at the edge of the table, giving it good accessibility to both the shelves and the AGC area.

The AGC has a fixture mounted on top of it. This fixture holds the HMI-panel in place to enable robotic assembly of the connectors into the panel, directly after they have been provided with the specified set of switches. By keeping the workpiece on the AGC, less robot motions are needed to assemble the panel, which otherwise would have had to be carried over from the AGC to the robot table. This should save time, as well as reducing the risk of the panel getting scratched or damaged in other ways. Another benefit is that less space is occupied on the robot table.

4.3 Assembly procedure

Due to the fact that the connectors snap into the dash from behind (see SOB, Appendix 4), it was decided that the switches also should be installed with a similar movement. By pushing the connector onto all four switches at the same time, as shown in Figure 5, the robot can easily put the connector into the panel afterwards without having to change grip. This is an effective method, but it means that the switch has to be placed upside-down in a very precise spot in order for the operation to work. Therefore, the robot also performs the “pick-and-place” task, to ensure that the correct switch is picked from the shelf and placed precisely on the right spot. This method differs from the current in use, in that it installs all of the switches in one push. See section 3.1 for comparison. Having the robot to take care of the switches, leaves the operator to assemble the SID-CP and installing the wiring loom.

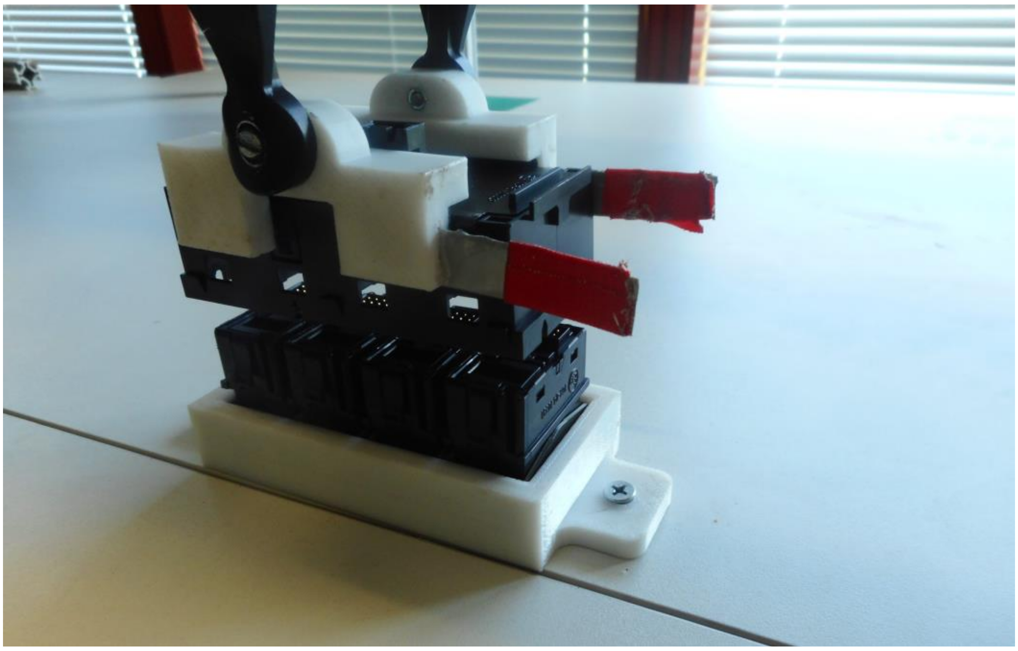

Figure 5. Method for assembling switches and connectors.

Since the material supply is such an important procedure in the work station and the switches have to be in an exact position, it was decided that the robot should, if possible, also pick them directly from the boxes. A few different methods were tested and analyzed and it was found that positioning the box at a relatively steep angle enabled the robot to easily pick the switch.

The design of the fingers and shelves forced the robot to position its gripper upside down when picking switches, in order to be able to maneuver between the shelves (see Figure 6). However, this is not a problem since the switches nevertheless need to be turned around in order for the assembly method to work. This type of movement also enables the shelf to be located close to the robot, saving space in the robot cell as well as giving the robot a few extra inches of range.

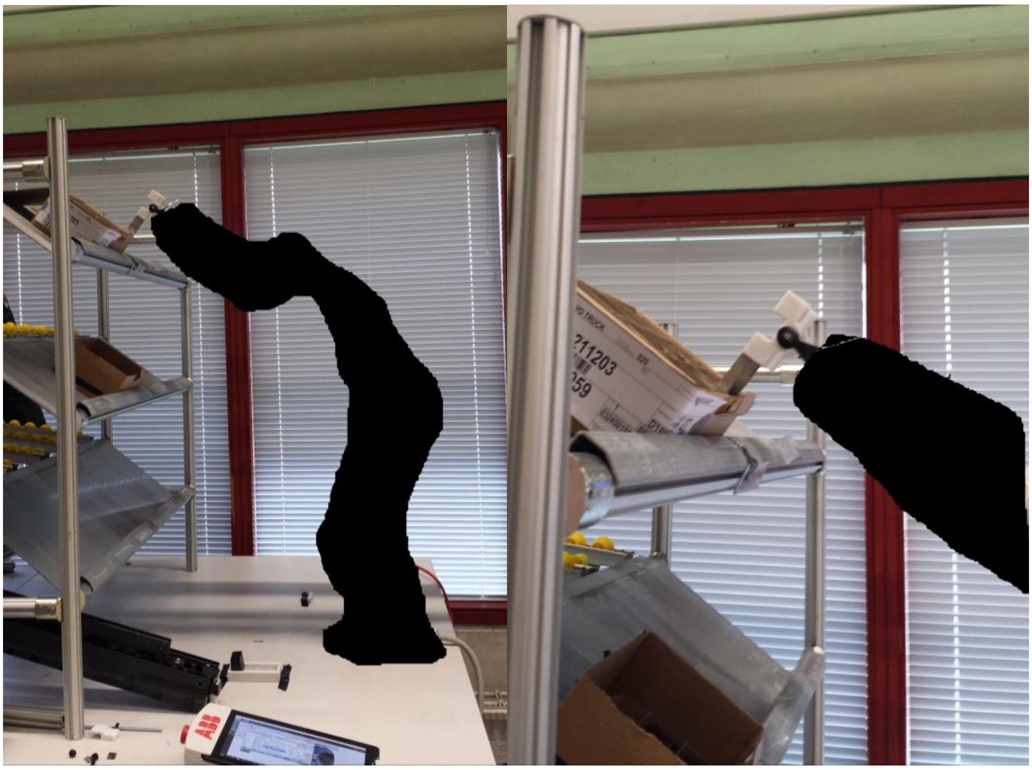

Figure 6. The robot picking switches from the shelves.

Since the precision of the AGC is poor (at best +/- 10 mm), the robot had to be used to positioning the panel correctly in order for the assembly to work. This was solved by enabling the bench on the AGC to slide slightly in all directions and mounting two handles on the bench, angled 90 degrees from each other. This allows the robot to use its gripper to fix the position, by opening and closing it on the handles. Since this operation only should be executed while the AGC is docked at the robot station, operator input via the pendant touch pad is needed before it can commence. As part of the program, the question “Is the AGC docked? Yes/No” is displayed every time the robot is about to start working on the AGC.

The connectors are located upside-down on the chute in order to slide downwards, allowing them to be picked by the robot and assembled directly without any relocation maneuver. This saves robot movements and time. Since the connectors always slides to the same spot, the same procedure can be used by the robot every time despite the lack of vision system. See section 4.6 for further details.

4.4 Gripper fingers

The fingers on the gripper have been designed to enable both grabbing a single switch or a connector. A thin extension of stainless steel was added to each finger to enable the robot to pick switches directly from the boxes. As the extensions are slightly curved, they help to nudge the switch into the correct position before the gripper is closed and the switch is lifted out of the box. The Catia model of the finger is seen in Figure 7 and the final version with extensions is seen in Figure 8.

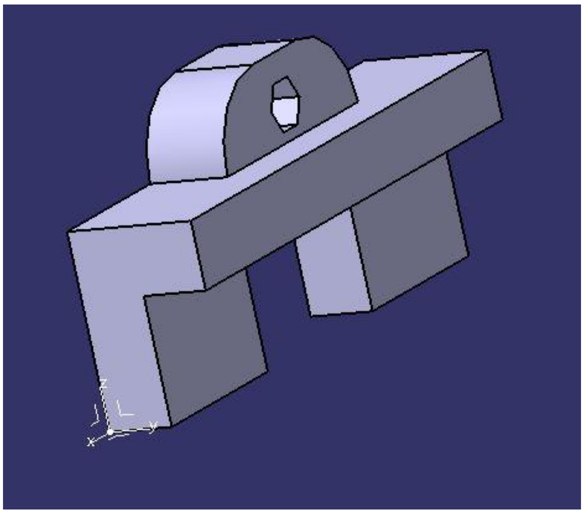

Figure 7. Catia model of the gripper finger.

The finger is L-shaped, so that it can push downwards with a great force while only using a small force to hold the connector. The fingers have been made slim to be able to maneuver in tight spaces when assembling the connector in the HMI-panel.

Figure 8. The final version of the fingers, mounted on the robot's gripper

A practical feature is the hexagon shaped hole that keeps the nut in place when the finger is mounted on the robot, so that one tool less is needed when attaching the fingers to the gripper and the nut is neatly recessed in the plastic material of the finger. Since the 3D-printed plastic that the finger is made of is quite slippery, some bits of rubber were glued on for added friction.

4.5 Fixtures

Fixtures are used to support the panels while the connectors, prepared with adequate switches, are pushed in by the robot from the back-side. The very same operation takes place in the current station, with the operator doing the work. The fixture in the current station is well suited for a collaborative station but since no such fixture was available for the project, we had to create our own version from scratch.

The irregular geometry of the panels made it hard to create a fixture in a single piece. The risk was obvious that a single piece fixture, despite meticulous measuring, would turn out to have poor stability in the end. It would also be hard to fit such an object within the 380 by 380 mm limits of the 3D-printer. A different solution, where the fixture consists of several individually adjustable fixture points, was constructed. These fixture points together form the fixture when they are placed on the right spots to support the panel.

A set of standardized fixture parts were drawn in Catia v5, consisting of:

- Sliding block
- Sliding rail
- Anchor

Figure 9 shows how the sliding block and rail fit together and form a fixture point with an adjustment range of 90 mm. The desired position is locked by tightening the nut and screw that connect the parts. This clamps the block in place.

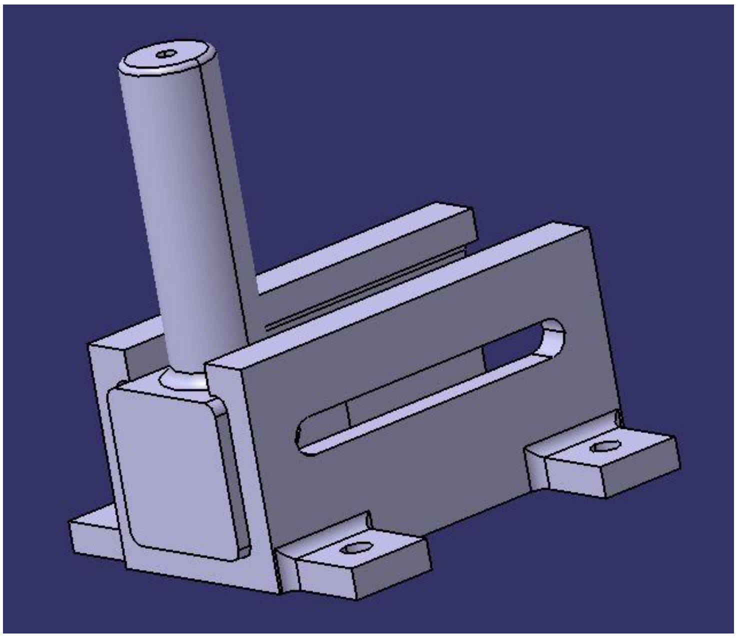

Figure 9. Sliding block and rail assembled in Catia v5. The threaded rod is not shown.

The anchor (see Figure 10) is a non-adjustable fixture point, which can’t be slid back and forth. It is used when several holes in panel line up on a straight line and adjustments are unnecessary. In each of the sliding blocks and anchors, a 100 mm threaded rod along with a locking nut was inserted. The nut serves as a height adjuster, to get the height for each fixture point right.

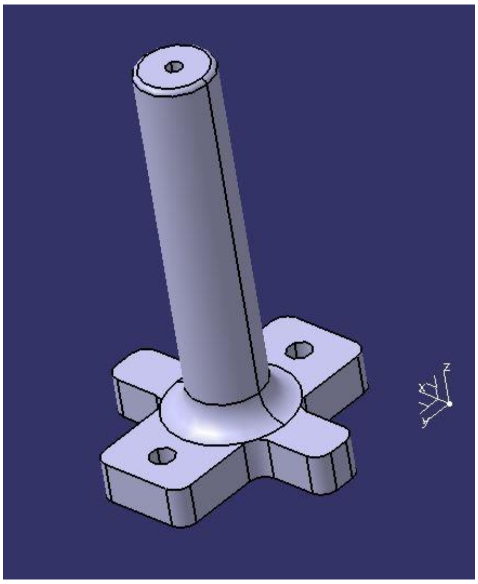

Figure 10. The anchor. The threaded rod is not shown.

Fixing the panel is done by turning the panel upside-down and sliding it onto the threaded rods on each fixture point. The panel then rests on the locking nuts. With the fixture points properly adjusted, a secure fixation that is suitable for robotic as well as manual assembly is obtained (see Figure 11). Another benefit is that the same fixture parts can be used for many other panels of different shapes and sizes, making it a flexible and scalable solution.

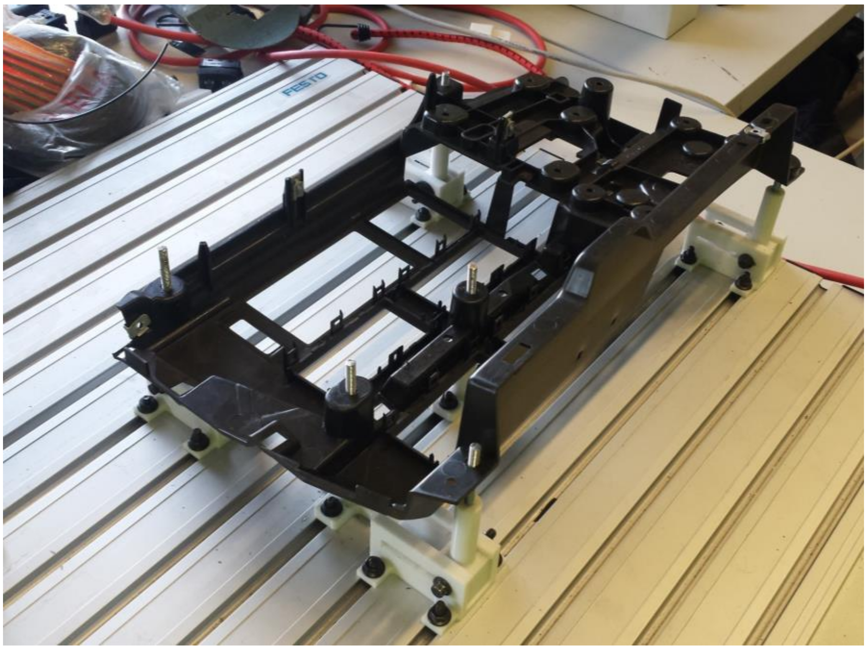

Figure 11. The complete fixture system holding the HMI-panel. Note the threaded rods that hold the panel in place.

Another fixture, which can be seen in Figures 5 and 12, was made to hold the switches in place as the robot places the connector on them from behind. The fixture has four slots where the switches are placed upside-down by the robot. A square pocket was made in each compartment to adapt the fixture to a special type of switch that has a safety to prevent accidental activation.

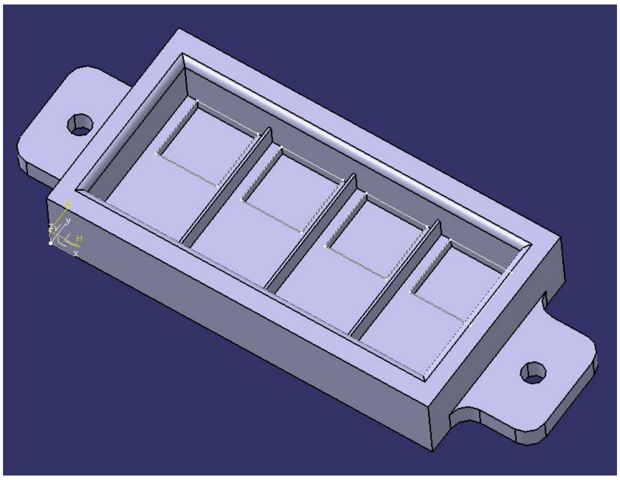

Figure 12. Fixture for the switches.

4.6 Material rack

A material rack was created by rebuilding a scrapped rack from the production line. The rack is built up by a system of aluminum profiles, connected with adjustable joints on each side. The joints are easily loosened with an Allen key, and can be put together in any configuration as long as it is a “box-shape”. By cutting the aluminum profiles to desired length, the rack was down-sized to fit the chosen concept (see concept 2 in Appendix 3), where the rack is situated on a table along with the robot.

Figure 13. Material rack.

A feature that can be noticed in Figure 13, is the relatively steep angle at which the shelves have been installed. This makes it easier for the robot to pick the switches from the box, particularly when the two top layers of switches have been emptied. If the shelves had been level, the gripper would have been at an awkward angle when picking the switch, making it impossible to pick the bottom layer.

An additional chute was added to feed the connectors to the robot. It consists of two roller tracks welded together in order to be wide enough. A guiding track is mounted above the roller tracks to ensure that the connectors smoothly slide down the track without sliding into the chute walls and sticking. The connectors are placed upside-down in the chute (see Figure 14), since the robot picks and then pushes the connector onto the switches from behind as described in section 4.2.

Figure 14. Chute with connectors.

4.7 Robot program

The robot moves to pre-programmed positions, gathered by manually jogging the robot to the position and saving it in the controller module.

To pick a switch from a box and place it in a fixture requires approximately eight positions. Since there are 27 switches in one box and 12 boxes on the storage shelves, at least 8*27*12 = 2592 positions are required just to pick and place the switches. On top of that there are positions for picking and assembling the connector and positioning the panel fixture, which combined would result in an unmanageable amount of positions if they were to be gathered by hand guiding the robot. The solution to the problem was to develop an algorithm that dynamically calculates the positions required to deliver an order. This way, the amount of code and data in the program could be drastically reduced to a more convenient amount.

The primary objective was not to create the fastest station possible, but the robot's movements are still somewhat customized to fit the specific purpose of each step in order to avoid time wastage. For example, different types of movements are used depending on the situation. Precision tasks use the Linear movement, a lower speed and high accuracy, while "transport" tasks use Joint movement, higher speeds and lower accuracy. If the "transport" task was performed the same way as precision tasks, the robot would be unnecessary slow and jerky. In other words, the program is adapted to be fast or precise when needed.

4.7.1 Positioning algorithms

In order for the robot to pick the right switch, each box has been given a number. Since each box only should contain one type of switch, the given number practically corresponds to a certain type of switch. Based on this information, an algorithm can calculate the position of the desired switch box. Inside each box, all the switches have been numbered, just like the boxes. Since the program keeps track of which switches it has picked before, another algorithm calculates where in each box the next switch is located. A schematic draft of these concepts can be seen in Figure 15. The algorithms can be found in Appendix 5, named "kartongkalk" and "knappkalk".

7	8	9
4	5	6
1	2	3

3	6	9	12
2	5	8	11
1	4	7	10

Figure 15. Schematic top-view of a box (to the left) and front-view of the shelves (to the right).

4.7.2 Assembly sequence

The following assembly tasks are performed by the robot:

1. The robot picks and places four switches in sequence, preparing one switch-group at a time.

2. After that the robot picks a connector, assembles it and then places it besides the AGC parking spot. The process is then repeated until all five groups has been completed and the AGC has arrived.

3. The robot pendant displays a message, asking the operator if the AGC is docked at the robot station. If yes, the bench relocation procedure is performed, as described in section 4.3.

4. The robot puts the five connectors with switches into the panel.

5. The robot starts on the next vehicle order.

The remaining tasks, such as installing SID-CP and connecting the wiring loom, are performed by the operator.

The complete code is found in Appendix 5.

5 Discussion

As discussed previously, the robot lacked any type of collaborative features, which disqualified it from working in a collaborative station. The task was solved by separating the the operator and robot, but at the same time this forced the objective of the work to be changed. Instead of a collaborative station, it became somewhat of a coexisting station. Though, it still serves well as a showcase for the technology.

The prototype robot hampered the project a great deal. The primary issue was the poor stability of the robot controller, frequently causing it to enter a failure state. This consumed a lot of time, since the robot had to be restarted and re-calibrated each time this happened. Another problem is that multiple softwares are used to control the robot. It is inconvenient to use up to three different softwares in order to jog the robot, record positions, run programs etc., especially since only one of them can be running at a time.

The robot also lacks power and force sensors, which makes us doubt the feasibility of making it a part of a collaborative station. There are other ways (see section 2.2) than power and force limiting to make a robot collaborative, but investing in a robot with power and force limiting is by far the safest option from a worker safety point of view since it stops immediately when it senses a collision. During a visit to Volvo Trucks engine factory in Skövde we got the chance to try a KUKA iiwa, a collaborative robot already available on the market. A light push anywhere on the robot arm caused the robot to stop and operation was only assumed after the operator had cleared the event log on the controller human-machine interface. The KUKA iiwa was used in an earlier thesis project in Pilot Plant and was given approval by the safety representatives of the plant [11].

The picking of switches from the boxes located on the material shelf posed a significant challenge. Even though we had made a special tool so the gripper could reach the switches in the box, it was hard to achieve the precision needed for assembling the switches and connectors. The switch was sometimes sheared into the wrong position as it was grabbed by the extensions on the gripper tool. This caused the switch to end up in the wrong position in the fixture.

Another material related issue that needs to be solved is how the robot should reach all of the switches. One way of solving this would be to make the robot movable, by for example mounting it on the AGC. This would enable the robot to cover a wider array of switch types. It would also be able to refill the material shelves with new boxes of switches. Another possible improvement is to place a curved shelf around the robot (as shown in concept 1, Appendix 3). This way, the robot could reach significantly more boxes with switches.

6 Conclusion and recommendations for further development

Our recommendations for further development of the station are:

- Change the robot to one with power and force limiting. Preferably one that is released on the market, which means that it has undergone extensive testing and debugging by the manufacturer. This would make a truly collaborative work station possible, like concept 1 (Appendix 3).

- Rework the Switchcalc software so that it can provide the robot with the switch configurations that are unique to every truck. This is a key step towards implementation into the real production environment.

- Use a suction cup to lift the switches out of the box. The suction cup has the benefit of being more precise compared to the gripper, which can easily shear smaller objects into the wrong position.

- Consider installing a vision system to work in conjunction with the robot. Assembling switches is a precision task. Even a small (< 5 mm) deviation from the pre-programmed positions causes a lot of disturbance in the process. A vision system can compensate for this.

To conclude the project, we return to the question asked in section 1.4:

Is the assembly of switches for the truck's dashboard a suitable task to automate?

Yes. As mentioned before, the current station suffers from poor ergonomics as well as quality issues. By automating some of the tasks with a collaborative robot several of these problems can be solved. We have shown that the robot is able to take over the most problematic tasks which are:

- **Picking the switch.** This improves quality as the risk for picking the wrong switch is reduced.

- **Preparing the connector module with switches.** This improves ergonomics as the operator doesn't have to exert pushing force with his hands over and over again. It should also solve the very frequent problem of switches not being pushed in hard enough to lock into place in the connector module. The robot's pushing force can be adjusted and the repeatability of robot movements is very good.

- **Placing the connector module in the panel section.** This further improves quality, since the risk of misplacement of the connectors is reduced.

Even though this is a pilot project with a rather narrowed down scope compared to the real production process, the potential that lies in robotic assembly of switches is obvious. The value-based development stages of Industry 4.0, described in section 2.3, emphasize the need of visibility, transparency, predictive capacity and adaptability. The implementation of collaborative automation should create an environment where such demands can be met. In any case, it liberates the human from a lot of monotonous tasks and should lead to a better use of human resources.

All in all, the project was a success. We have shown that a robot is able to carry out most of the tasks at the current station. We have furthermore identified and eliminated a particularly non-value adding operation, namely step 2 in the SOB for switch assembly (Appendix 4), where the switches must be sorted by the worker assembling the connector. This means that the switches went from being perfectly organized on the shelves to being mixed into a mess by the worker doing the kitting procedure, and then they become organized again as the other worker sorts them prior to assembly.

We wish AB Volvo good luck in the continued process of implementing a collaborative work station for switch assembly and look forward to seeing the result in the future!

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Appendices

Appendix 1 - Interview with production personnel

An interview was made with a team leader and workers who have experience from the current station. The purpose was to find out as much as possible about the problems with the current station and possibly receive input about how to solve them. A summary of the interview can be read below:

How often are switches wrongly placed in the connector?

It happens 2-3 times per week if experienced persons work at the station. Much worse with the rookies.

How long does it take to correct the error?

It takes around 5 minutes. The dashboard needs to be taken apart.

How often does it happen that switches are insufficiently pressed into the connector?

It happens every day. It is so common that we don't have time to report it in QULIS.

What ergonomic problems do you experience with the current station?

Assembly of switches:

- Strenuous for the hands when pushing the switches into the connector.
- The covers (blind plugs) are much harder to press in than the switches.

Kitting the switches:

- You have to walk back and forth in the aisle to dispose of cardboard and other garbage all the time.
- A lot of cardboard boxes have to be opened every day.

Other parts of the assembly process (placing and screwing the SID/CP, connecting the wiring loom) are OK. No problems to speak of.

What other problems do you experience with the current station?

- It takes a lot of time to find and correct faults due to incorrect placement of the switch. You have to go back in the production documents and find the right position for the switch.
- Some variants of switches are not included in the pick-to-light system, then you have to look for their article number on the shelf. This takes time.
- The panels are sometimes mixed up so that the wrong panel is mounted on a dashboard. Then you have to remove the dashboard from the truck. It takes 10 minutes.
- There is a hook-like tool that can be used to remove the hardwired type of switch, if it has been placed incorrectly. The problem is that you will most likely destroy the panel if you use it. Therefore, it is considered more efficient to take apart the dashboard and remove the panel and thereafter remove the incorrect switch from behind.

- Switchcalc documents are sometimes mixed up, since they are printed on paper and laid in bundles at the station. The kitting procedure is not affected by this because of the pick-to-light system, but the person assembling the panel will receive the wrong document.

Appendix 2 - LoA-Matrix

LoA-matrix

LoA assembly of buttons into connectors

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	
LoAphysical									
7									
6									
5									
4									
3									
2									
1	4	2							100%
	1	2	3	4	5	6	7	LoA cognitive	
	66%	33%							

LoA assembly of buttons into panels

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	
LoAphysical									
7									
6									
5									
4									
3	1								12.5%
2									
1	3	4							87.5%
	1	2	3	4	5	6	7	LoA cognitive	
	50%	50%							

LoA analysis

Assembly of switches into connectors

Step 1 - get “swichcalc” to the chassis number (cognitive level 1, physical level 1)

Step 2 – sort the switches (cognitive level 1, physical level 1)

Step 3 – place the switches in the fixture (cognitive level 2, physical level 1)

Step 4 – assemble the all the switches in the panel according to “switchcalc” (cognitive level 2, physical level 1)

Step 5 – gently push the switches until locked, check (cognitive level 1, physical level 1)

Step 6 – check all the switches according to “switchcalc” (cognitive level 1, physical level 1)

Assembly of connectors into panels

Step 1 – Place the panel in the fixture (physical level 1, cognitive level 1)

Step 2 – Turn fixture and assemble SID-CP and switch panel, (physical level 1, cognitive level 1)

Step 3 – Turn fixture gently and assemble panels (physical level 3, cognitive level 1)

Step 4 – Assemble cables (physical level 1, cognitive level 1)

Step 5 – Assemble prepared connectors according to “switchcalc” (physical level 1, cognitive level 2)

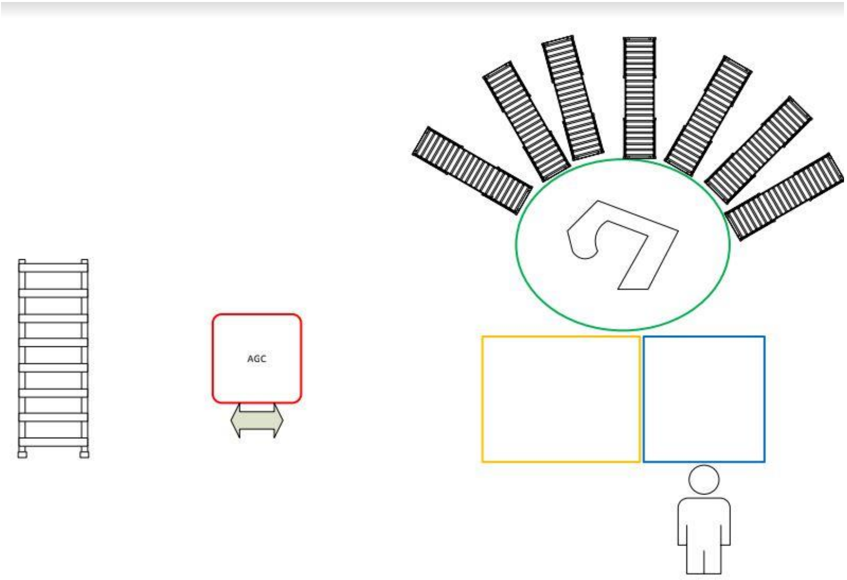
Step 6 – Assemble switches on outboard panel according to “switchcalc” (physical level 1, cognitive level 2)

Step 7 – Assemble switches on inboard panel according to “switchcalc” (physical level 1, cognitive level 2)

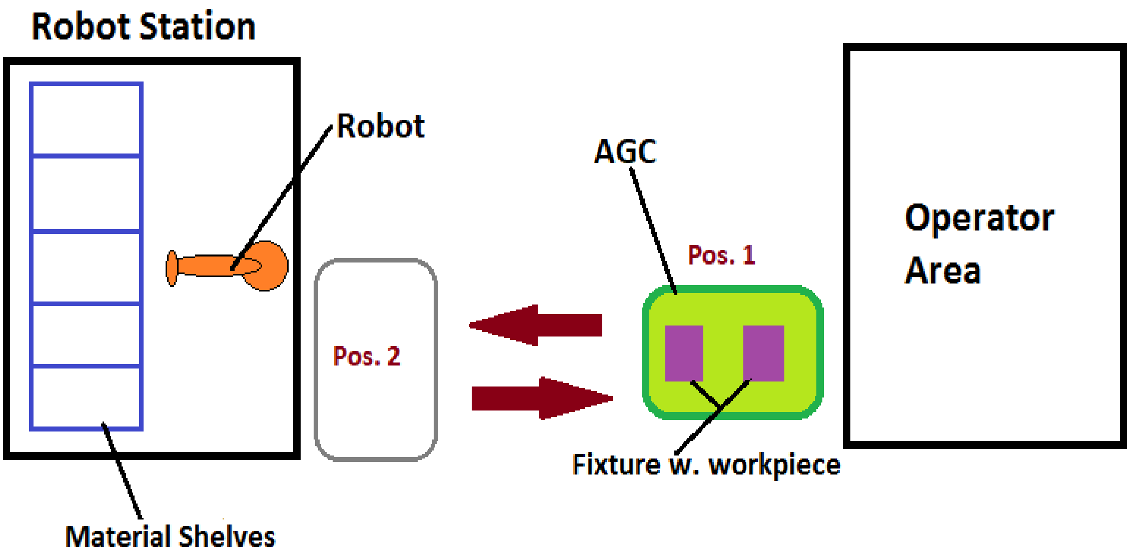
Step 8 – Assemble switches on lower panel according to “switchcalc” (physical level 1, cognitive level 2)

Appendix 3 - Concepts

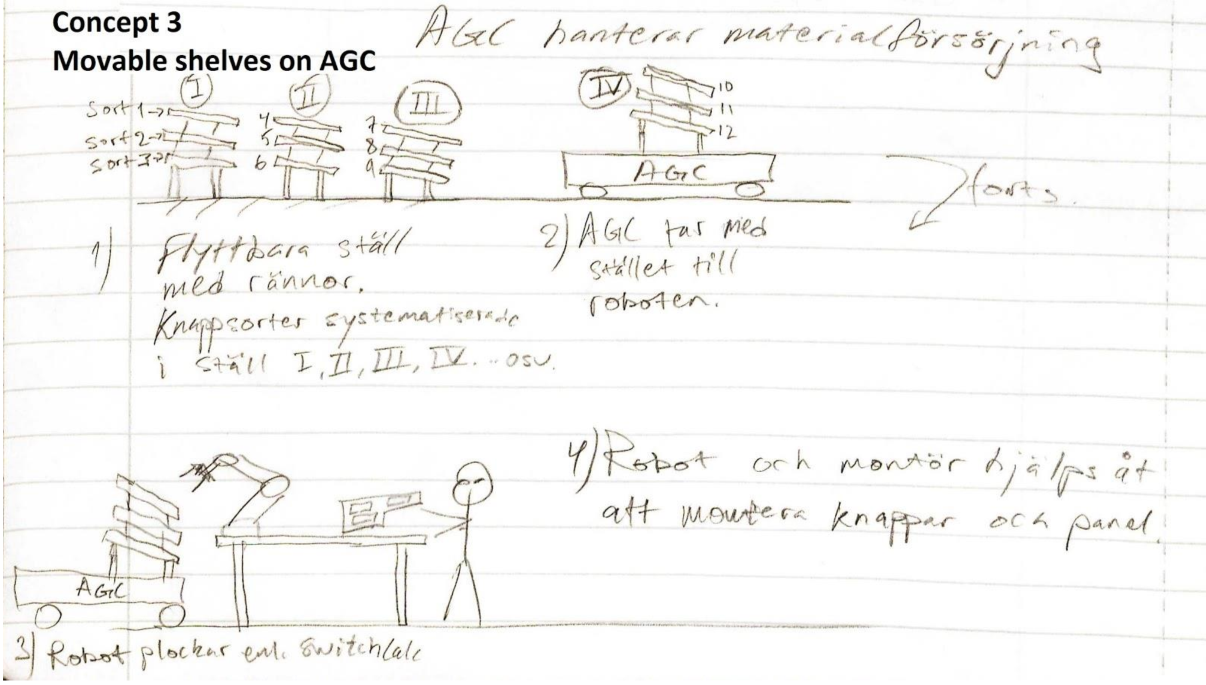
Concept 1



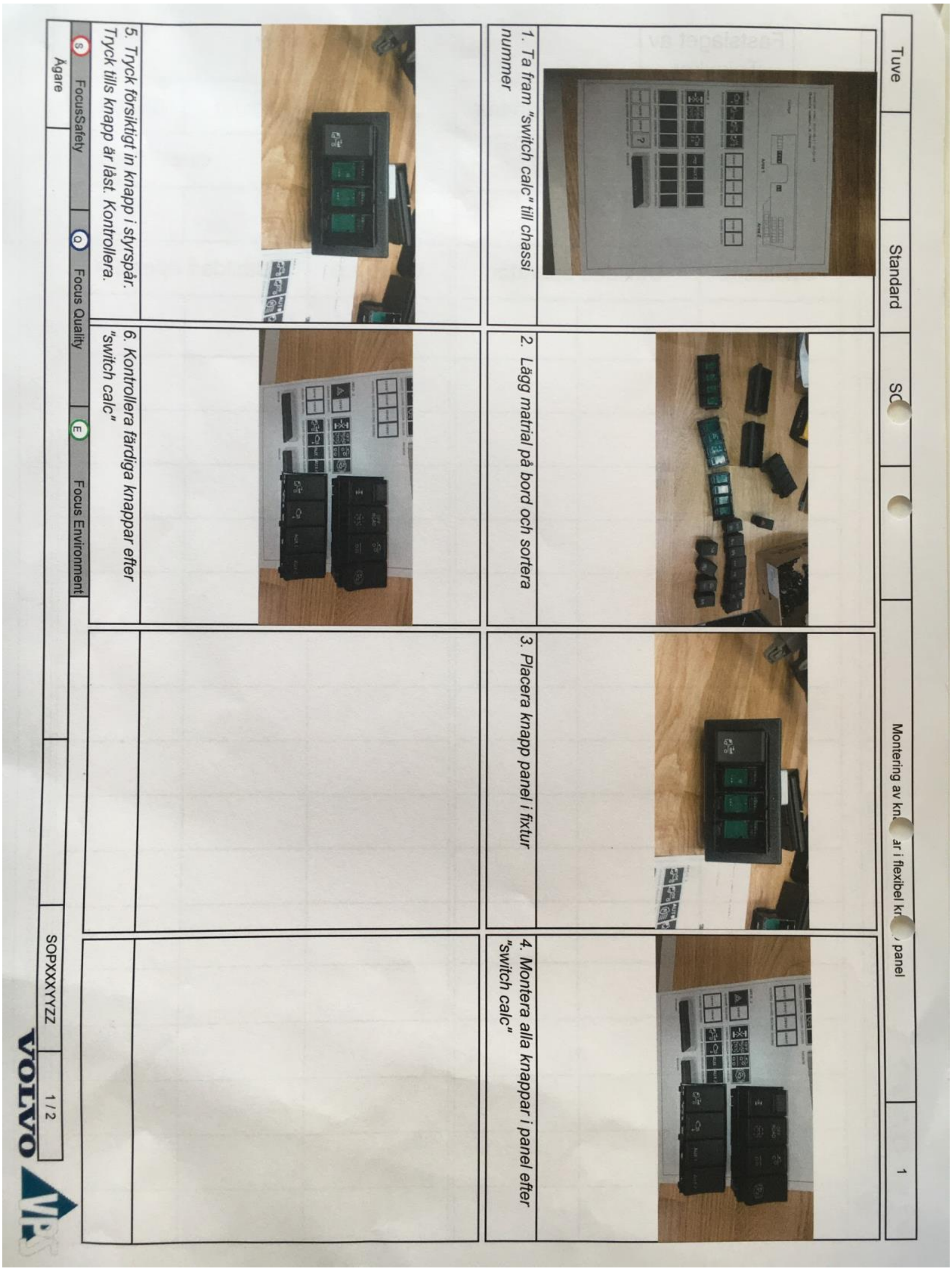
Concept 2



Concept 3


Concept 3
Movable shelves on AGC
AGC hanterar materialförsörjning
I
II
III
IV
Sort 1
Sort 2
Sort 3
4
5
6
7
8
9
10
11
12
AGC
forts.
1) Flyttbara ställ med rännor. Knappsorter systematiserade i ställ I, II, III, IV... osv.
2) AGC tar med stället till roboten.
4) Robot och montör hjälps åt att montera knappar och panel.
AGC
3) Robot plockar enl. Switchlalc

Appendix 4 - SOB for switch assembly



Tuve | Standard | SC | Montering av kn ar i flexibel kr panel | 1

1. Ta fram "switch calc" till chassi nummer
2. Lägg matrial på bord och sortera
3. Placera knapp panel i fixtur
4. Montera alla knappar i panel efter "switch calc"
5. Tryck försiktigt in knapp i styrspår. Tryck tills knapp är låst. Kontrollera.
6. Kontrollera färdiga knappar efter "switch calc"

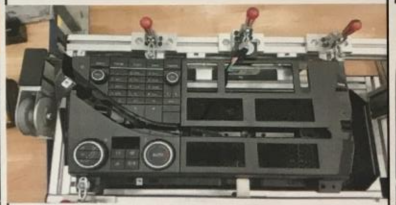
S FocusSafety | Q Focus Quality | E Focus Environment

Ägare | SOPXXXYYZZ | 1 / 2

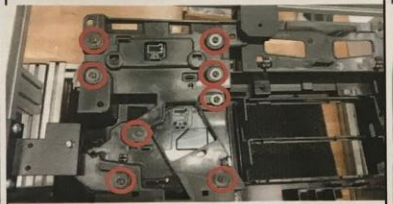
VOLVO

Tuve		Standard	SC		Montering av knappa h förvaringsf på paneler	1

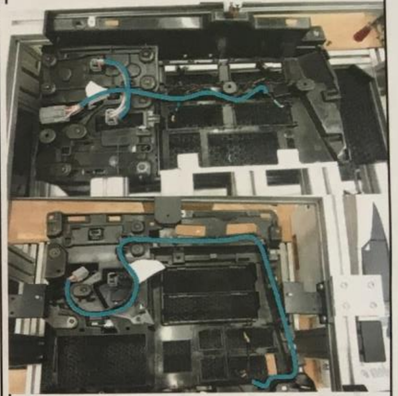
1. Placera panel i fixtur. FH övre bild. FM nedre bild.



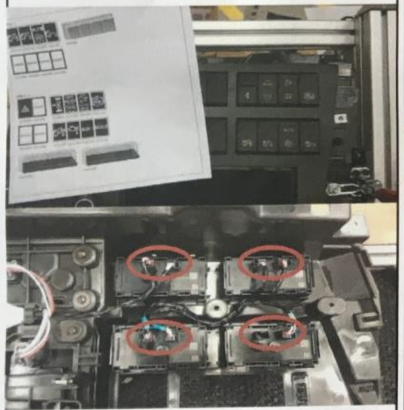
2. Vrid fixtur och montera SID-CP och strömställar panel.



3. Vrid fixtur föriktigt och skruva fast paneler med 8 st 976162.

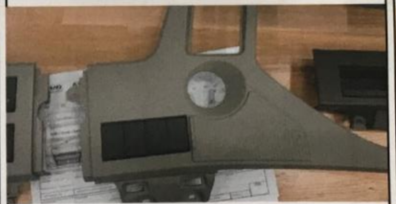


4. Montera kabelmatta. FH övre bild. FM nedre bild.



5. Montera förarbetade knapp paneler enligt "switch calc" och kontaktera.

6. Montera knappar/fack på outboard panel enligt "switch calc".



7. Montera knappar/fack på inboard panel enligt "switch calc".

8. Montera knappar/fack på lower panel enligt "switch calc". (FM).

Appendix 5 - The Complete Program Code

Please note, comments made in the code are in Swedish. They always begin with an exclamation point and have been colored green to help the reader separate them from the actual code.

```
MODULE MainModule

CONST robtarget start := [[385.0855,-
38.29565,300.8027],[0.02139716,-0.7038966,-0.709962,-0.005074954],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]];

CONST robtarget lada1{5} := [[[321.8048,-
43.23566,433.434],[0.3292671,0.6525096,0.629023,0.264848],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[372.2957,-
34,470.4624],[0.5162631,0.5286545,0.5094816,0.4409368],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[303.2145,211.2818,325],[0.6251729,0.3045853,0.2922195,0.
6565016],[0,4,4,1],[8999999000,8999999000,8999999000,8999999000,8999
999000,8999999000]],[[376.4767,209.3895,276],[0.6270711,0.2886528,0.
2877997,0.6638017],[0,4,4,1],[8999999000,8999999000,8999999000,89999
99000,8999999000,8999999000]],[[392.843,208.5403,253],[0.6270577,0.2
886517,0.2877696,0.6638278],[0,4,4,1],[8999999000,8999999000,8999999
000,8999999000,8999999000,8999999000]]];

CONST robtarget lada2{5} := [[[270.6144,-
60.59306,495.3386],[0.4248951,0.602356,0.59654,0.3174452],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[272.5563,-
66.51031,692.5614],[0.7671537,0.294857,0.2705759,0.5013214],[-
1,4,4,1],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[370.5906,233,615],[0.6521468,0.3121181,0.2729089,0.63467
12],[0,4,4,1],[8999999000,8999999000,8999999000,8999999000,899999900
0,8999999000]],[[373,232,590],[0.6524745,0.3095721,0.2673424,0.63794
22],[0,4,4,1],[8999999000,8999999000,8999999000,8999999000,899999900
0,8999999000]],[[386.6657,231,566.7095],[0.6524014,0.3096303,0.26728
2,0.638014],[0,4,4,1],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]]];

CONST robtarget lada3{5} := [[[272.2024,-
40.41478,522.3676],[0.2951885,0.6451455,0.6692398,0.2208373],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[250.8121,-
7.548837,925],[0.7169799,0.2461745,0.2819268,0.5880946],[-
```

```
1,4,4,1],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[364.1101,206.0878,910],[0.626263,0.280938,0.2973667,0.66
36577],[0,4,4,1],[8999999000,8999999000,8999999000,8999999000,899999
9000,8999999000]],[[368,206.4229,903],[0.6262397,0.2810006,0.2973428
,0.663664],[0,4,4,1],[8999999000,8999999000,8999999000,8999999000,89
99999000,8999999000]],[[384,210.2608,884],[0.6296581,0.2892435,0.289
5194,0.6603389],[0,4,4,1],[8999999000,8999999000,8999999000,89999990
00,8999999000,8999999000]]];

CONST robtarget fixtur{3} := [[[318.0574,-
29,230],[0.01896371,0.6960717,0.7175487,0.01575974],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[292,-
29,230],[0.01875838,0.7085894,0.7051851,0.01622036],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[292,-
29,198],[0.01875838,0.7085894,0.7051851,0.01622036],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]]];

CONST robtarget reine_pos{13} :=
[[[284.77,345.8412,310.7165],[0.1388623,0.717048,0.6740604,0.1104622
],[0,3,5,0],[8999999000,8999999000,8999999000,8999999000,8999999000,
8999999000]],[[323.0484,335.0845,225.8546],[0.09785785,0.7245526,0.6
728464,0.1128052],[0,3,5,0],[8999999000,8999999000,8999999000,899999
9000,8999999000,8999999000]],[[317.6927,334.9301,243.1663],[0.097803
62,0.7245868,0.672807,0.1128678],[0,3,5,0],[8999999000,8999999000,89
99999000,8999999000,8999999000,8999999000]],[[214.474,342.8565,211.3
577],[0.09777009,0.7245902,0.6727747,0.1130672],[0,3,5,0],[899999900
0,8999999000,8999999000,8999999000,8999999000,8999999000]],[[206.378
6,342.5114,260.285],[0.0977032,0.7245944,0.6727849,0.113038],[0,3,5,
0],[8999999000,8999999000,8999999000,8999999000,8999999000,899999900
0]],[[263.6786,-
28.83849,261.2706],[0.007332374,0.7105446,0.7035499,0.009499918],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[268.6459,-35.66047,234.3434],[0.007653907,-0.7128747,-
0.7011331,-0.01278666],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[262.806,-
34.46053,240],[0.0122422,0.7144755,0.6991259,0.02445018],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[264.3863,-
34.16782,199],[0.01308435,0.7144668,0.6990931,0.02519638],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[260.9089,-
35.13171,260.7926],[0.01308851,0.7144772,0.6990825,0.02519297],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[180.3477,154.4523,265.3092],[0.005430026,0.7022317,0.711
```

```
7317,0.0167086],[0,3,5,0],[8999999000,8999999000,8999999000,89999990
00,8999999000,8999999000]],[[8.118618,246.1835,265.3644],[0.00568202
2,-0.7207054,-0.6930893,-
0.01336319],[0,3,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[8.290232,246.6727,200.2051],[0.005795712,-
0.7207818,-0.6930072,-
0.01345121],[0,3,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]]];

    CONST robtarget fixfix_pos{9}:=[[[303.6729,-
27.8293,299.8277],[0.01142954,0.7156997,0.6982924,-0.005566601],[-
1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[186.4923,218.3816,348.4895],[0.0215142,-0.3969096,-
0.9166881,-
0.04102164],[0,4,5,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-
574.192,75.79119,415.5868],[0.01925424,0.7087663,-0.704911,-
0.01949424],[1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-
580.4013,73.50962,201.6933],[0.006427277,0.7054466,-0.7086965,-
0.007287382],[1,4,4,0],[8999999000,8999999000,8999999000,8999999000,
8999999000,8999999000]],[[-
579.4252,73.74341,244.4939],[0.005774564,-
0.6984692,0.7154976,0.01306745],[1,3,4,0],[8999999000,8999999000,899
9999000,8999999000,8999999000,8999999000]],[[-
688.3387,72.44247,234.5339],[0.01126842,-0.005876088,-0.9996514,-
0.02314459],[1,3,5,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-695.8268,69.38728,200.5129],[0.001066436,-
0.001068004,0.9995661,0.0294171],[1,3,5,0],[8999999000,8999999000,89
99999000,8999999000,8999999000,8999999000]],[[-
695.8535,68.7247,250.97],[0.003563538,-
0.0004139488,0.9995611,0.02940521],[1,3,5,0],[8999999000,8999999000,
8999999000,8999999000,8999999000,8999999000]],[[-
556.8924,62.68504,441.7726],[0.04735444,0.692865,-0.7192108,-
0.02077315],[1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]]];

    CONST robtarget HMI_pickpos{2}:=[[[-
7.944385,246.6993,264.7115],[0.01321358,-
0.007508893,0.9998779,0.00364653],[1,3,5,0],[8999999000,8999999000,8
999999000,8999999000,8999999000,8999999000]],[[-
1.019499,245.2968,215.6969],[0.01591936,0.006844058,0.9998079,-
0.009162919],[1,3,5,0],[8999999000,8999999000,8999999000,8999999000,
8999999000,8999999000]]];

    CONST robtarget swich_knuff{3} := [[[409.4877,-
55.19247,200.8839],[0.004700726,0.7094779,0.7047113,0.0009865471],[-
1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
```

```
9999000]],[[385,-
55.01092,200.6748],[0.004783639,0.7094963,0.7046921,0.001065014],[-
1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]],[[403.9784,-55.2263,239.1228],[0.001888211,-0.7079382,-
0.7062334,-0.007374845],[-
1,4,4,0],[8999999000,8999999000,8999999000,8999999000,8999999000,899
9999000]]];

    CONST robtarget HMI_assypos{8}:=
[[[-250.2136,144.0853,400.9543],[0.006523445,-
0.2933462,0.9559139,0.01157872],[1,3,5,0],[8999999000,8999999000,899
9999000,8999999000,8999999000,8999999000]],[[-552.7482,-
94.91158,380.4999],[0.004329833,-0.008087426,0.9999465,-
0.004790489],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,
8999999000,8999999000]],[[-557.8058,-
75.69527,307.9093],[0.02945637,-0.001611816,0.9979571,-
0.05666838],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-557.4872,-76.31477,302.5648],[0.02943455,-
0.001610889,0.9979575,-
0.05667411],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-557.4008,-92.71252,304.054],[0.0294029,-
0.002328471,0.9991878,-
0.02745527],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-555.8884,-94.16396,278.9508],[0.02932682,-
0.002317089,0.999188,-
0.02752906],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-558.2192,-91.90554,320.0029],[0.02933917,-
0.002286293,0.9991877,-
0.02752963],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-522.7152,-87.15929,400],[0.008809363,-
0.004229147,0.9994822,-
0.03065599],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]]];

    CONST robtarget HMI_melpos := [[-400,-120,380],[0.004329833,-
0.008087426,0.9999465,-
0.004790489],[2,4,6,0],[8999999000,8999999000,8999999000,8999999000,
8999999000,8999999000]];

    CONST robtarget Outboard_assypos{9}:=
[[[-
25.49222,535.9868,340.0576],[0.01928185,0.004557044,0.9997221,0.0127
7177],[1,3,5,0],[8999999000,8999999000,8999999000,8999999000,8999999
000,8999999000]],[[-
434.766,431.7728,358.9312],[0.0008749708,0.2635522,-0.9646364,-
0.004008845],[1,3,5,0],[8999999000,8999999000,8999999000,8999999000,
8999999000,8999999000]],[[-632.624,224.1792,339.4495],[0.04958315,-
0.7260967,0.6847175,-
```

```
0.03856262],[1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-623.657,213.4874,288.505],[0.05632371,-
0.7214402,0.6887913,-
0.04379765],[1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-620.6149,212.3888,267.446],[0.05617747,-
0.7213982,0.6888574,-
0.04363836],[1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-611.5876,212.6878,274.783],[0.05615796,-
0.7214134,0.6888484,-
0.04355228],[1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-611.5876,212.6878,252.783],[0.05615796,-
0.7214134,0.6888484,-
0.04355228],[1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-611.5876,212.6878,300.783],[0.05615796,-
0.7214134,0.6888484,-
0.04355228],[1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]],[[-619.5992,209.8929,371.5648],[0.07328749,-
0.7238587,0.6844259,-
0.04710406],[1,3,4,0],[8999999000,8999999000,8999999000,8999999000,8
999999000,8999999000]]];



VAR robtarget fix_kopia{3} := fixtur;
VAR robtarget lada_kopia{5};
VAR bool result;

VAR num kartong{20}:=  [1,2,5,7,
                        3,11,9,10,
                        6,4,8,12,
                        5,11,9,10,
                        7,2,3,6];
VAR num order :=1;
VAR num test_trunc := 0;
VAR num test_mod := 0;
VAR num knapp_counter{12};
VAR bool init := TRUE;

VAR robtarget skugg_pos1 ;!reine
VAR robtarget skugg_pos2 ;
VAR byte contact_count := 1;

VAR robtarget pick_pos1 ;
VAR robtarget pick_pos2 ;
VAR robtarget HMI_pos_kopia{8};
VAR byte assy_count:=1;
VAR num pickup_offset := 0;
```

```
VAR num HMI_offs_x := 0;
VAR num HMI_offs_y := 0;

PROC main()
    IF init THEN
        set_init;
        init := FALSE;
    ENDIF
    FOR i FROM 1 TO 5 DO
        FOR k FROM 1 TO 4 DO
            kartong_kalk;
            knapp_kalk;
            switchplock;
            fixkalk(k);
            switchfix;
            order := order+1;
        ENDFOR
        MoveJ start, v60, z1,tool0;
        switch_knuff;
        reine;
    ENDFOR
    fixfix;
    FOR p FROM 1 TO 4 DO !montering av 4 kontakter i HMI-panel
        HMIassy;
    ENDFOR
    outboard_assy;
    contact_count := 0;
    order := 0;
ENDPROC

PROC switch_knuff()
    MoveL swich_knuff{1}, v30, z1,tool0;
    MoveL swich_knuff{2}, v30, z1,tool0;
    MoveL swich_knuff{3}, v30, z1,tool0;
ENDPROC
PROC switchfix()
    MoveJ fix_kopia{1}, v40, z1, tool0;
    MoveL fix_kopia{2}, v20, z1, tool0;
    MoveL fix_kopia{3}, v20, z1, tool0;
    WaitRob \ZeroSpeed;
      result := SG70_SetFingerSpan(23);
ENDPROC
PROC fixkalk(num k)
        fix_kopia{1} := Offs(fixtur{1},24*(k-1),0,0);
        fix_kopia{2} := Offs(fixtur{2},24*(k-1),0,0);
        fix_kopia{3} := Offs(fixtur{3},24*(k-1),0,0);
ENDPROC
PROC switchplock()
```

```
    MoveJ start, v60, z1, tool0;
     MoveJ lada_kopia{1}, vmax, z10, tool0;
     MoveJ lada_kopia{2}, vmax, z10, tool0;
     MoveJ lada_kopia{3}, v80, z1, tool0;
    WaitRob \ZeroSpeed;
     result := SG70_SetFingerSpan(5);
    MoveL lada_kopia{4}, v20,z1,tool0;
    WaitRob \ZeroSpeed;
     result := SG70_SetFingerSpan(23);
    MOVEL lada_kopia{5}, v20, z1, tool0;
    WaitRob \ZeroSpeed;
     result := SG70_SetFingerSpan(15);
    MoveL lada_kopia{4} ,v20, z1, tool0;
    MoveL lada_kopia{3}, v80, z5, tool0;
    MoveJ lada_kopia{2}, vmax, z10, tool0;
    MoveJ lada_kopia{1}, vmax, z20, tool0;
     MoveJ start, v100, z1, tool0;
ENDPROC

PROC kartong_kalk() !Intressant metod för att kalkylera kartongens
offset beroende på dess index.
        !Här beräknas kartongens rad.
        TEST kartong{order} MOD 3
            CASE 1: lada_kopia := lada1;
            CASE 2: lada_kopia := lada2;
            CASE 0: lada_kopia := lada3;
        ENDTEST
        test_trunc := Trunc((kartong{order}-1)/3);  !Här beräknas
kartongens kolonn.
        lada_kopia{3} := Offs(lada_kopia{3},0,-202*test_trunc,0);
        lada_kopia{4} := Offs(lada_kopia{4},0,-202*test_trunc,0);
        lada_kopia{5} := Offs(lada_kopia{5},0,-202*test_trunc,0);
ENDPROC

PROC knapp_kalk() !Kalkylerar offset i kartongen.
    test_mod := knapp_counter{kartong{order}} MOD 3;
    test_trunc := Trunc((knapp_counter{kartong{order}})/3);
    lada_kopia{3} := Offs(lada_kopia{3},36*test_trunc,-
53*test_mod,27*test_trunc);
    lada_kopia{4} := Offs(lada_kopia{4},36*test_trunc,-
53*test_mod,29*test_trunc);
    lada_kopia{5} := Offs(lada_kopia{5},36*test_trunc,-
53*test_mod,28*test_trunc);
    knapp_counter{kartong{order}} := knapp_counter{kartong{order}} +
1;
ENDPROC
PROC reine()
        skugg_pos1 := Offs(reine_pos{12},0,(contact_count-1)*70,0);
```

```
        skugg_pos2 := Offs(reine_pos{13},0,(contact_count-1)*70,0);

           MoveJ reine_pos{1}, v100, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(45);
           MoveL reine_pos{2}, v30, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(31);
           MoveJ reine_pos{3}, v30, z1, tool0;
        MoveJ reine_pos{4}, v60, z1, tool0;
           MoveJ reine_pos{5}, v100, z10, tool0;
           MoveJ reine_pos{6}, v100, z10, tool0;
           MoveJ reine_pos{7}, v60, z10, tool0;
           MoveJ reine_pos{8}, v30, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(36);
           MoveJ reine_pos{9}, v10, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(31);
           MoveJ reine_pos{10}, v30, z1, tool0;
           MoveJ reine_pos{11}, v60, z1, tool0;
           MoveJ skugg_pos1, v60, z1, tool0;
           MoveJ skugg_pos2, v60, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(42);
        MoveJ skugg_pos1, v60, z1, tool0;

        contact_count := contact_count + 1;
     ENDPROC
PROC HMIassy()
        TEST assy_count
                    CASE 2:
                        HMI_offs_x := -114;
                        HMI_offs_y := 0;
                    CASE 3:
                        HMI_offs_x := -114;
                        HMI_offs_y := -81;
                    CASE 4:
                        HMI_offs_x := 0;
                        HMI_offs_y := -81;
                    CASE 5:         !Nollställning av
monteringsoffsetter inför nästa uppdrag.
                        assy_count := 0;
                        pickup_offset :=0;
                        HMI_offs_x := 0;
                        HMI_offs_y := 0;
        ENDTEST
        pickup_offset := 70 * (assy_count-1);
```

```
        FOR r FROM 1 TO 8 DO !Modifierar kopian så att varje
kontakts position blir rätt.
            HMI_pos_kopia{r} := Offs(HMI_assypos{r}, HMI_offs_x,
HMI_offs_y, 0);
        ENDFOR

        pick_pos1 := Offs(HMI_pickpos{1},0,pickup_offset,0);
        pick_pos2 := Offs(HMI_pickpos{2},0,pickup_offset,0);

        MoveJ pick_pos1, v100, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(40);
           MoveJ pick_pos2, v80, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(21);
        WaitTime 0.5;

           MoveJ HMI_pos_kopia{1}, vmax, z10, tool0;
        MoveJ HMI_melpos, vmax, z10, tool0;
           MoveJ HMI_pos_kopia{2}, vmax, z10, tool0;
           MoveJ HMI_pos_kopia{3}, vmax, z1, tool0;
           MoveJ HMI_pos_kopia{4}, v60, z1, tool0;
           WaitRob \ZeroSpeed;
           result := SG70_SetFingerSpan(40);
           MoveJ HMI_pos_kopia{5}, v40, z1, tool0;
           MoveJ HMI_pos_kopia{6}, v80, z1, tool0;
           MoveJ HMI_pos_kopia{7}, vmax, z1, tool0;
           MoveJ HMI_pos_kopia{8}, vmax, z1, tool0;
        assy_count := assy_count + 1;
ENDPROC

PROC outboard_assy () ! Outboard-panelen är ett specialfall och
följer ett separat monteringsprogram enligt nedan.

    pick_pos1 := Offs(HMI_pickpos{1},0,280,0);
    pick_pos2 := Offs(HMI_pickpos{2},0,280,0);

    MoveJ pick_pos1, v100, z1, tool0; !Plockar upp kontaktstycke
från bordet
    WaitRob \ZeroSpeed;
    result := SG70_SetFingerSpan(40);
    MoveJ pick_pos2, v60, z1, tool0;
    WaitRob \ZeroSpeed;
    result := SG70_SetFingerSpan(21);
    WaitTime 0.5;
```

```
    MoveJ Outboard_assypos{1}, v80, z20, tool0; !Montering i
Outboard.
      MoveJ Outboard_assypos{2}, vmax, z20, tool0;
    MoveJ Outboard_assypos{3}, vmax, z20, tool0;
    MoveJ Outboard_assypos{4}, v80, z1, tool0;
    MoveJ Outboard_assypos{5}, v40, z1, tool0;
    WaitRob \ZeroSpeed;
    result := SG70_SetFingerSpan(40);
    MoveJ Outboard_assypos{6}, v40, z1, tool0;
    MoveJ Outboard_assypos{7}, v60, z1, tool0;
    MoveJ Outboard_assypos{8}, v100, z20, tool0;
    MoveJ Outboard_assypos{9}, v100, z20, tool0;
ENDPROC

PROC set_init()
    FOR a FROM 1 TO 12 DO
        knapp_counter{a} := 0;
    ENDFOR
    knapp_counter{4} := 6;
    WaitRob \ZeroSpeed;
      result := SG70_SetFingerSpan(45);
ENDPROC
PROC fixfix()
        VAR num answer;
        TPReadFK answer, "Är AGC:n dockad?", "Ja",
        "Nej", stEmpty, stEmpty, stEmpty;

        IF answer = 1 THEN
               MoveJ fixfix_pos{3}, vmax, z20, tool0;
               WaitRob \ZeroSpeed;
               result := SG70_SetFingerSpan(68);
               MoveJ fixfix_pos{4}, v80, z1, tool0; !Tvärgående
handtag
               WaitRob \ZeroSpeed;
               result := SG70_SetFingerSpan(5);
               WaitRob \ZeroSpeed;
            WaitTime 0.5;
               result := SG70_SetFingerSpan(68);
               MoveJ fixfix_pos{5}, v80, z1, tool0;
               MoveJ fixfix_pos{6}, v80, z1, tool0;
               MoveJ fixfix_pos{7}, v80, z1, tool0; !Längsgående
handtag
               WaitRob \ZeroSpeed;
               result := SG70_SetFingerSpan(5);
               WaitRob \ZeroSpeed;
            WaitTime 0.5;
               result := SG70_SetFingerSpan(68);
               MoveJ fixfix_pos{8}, v100, z20, tool0;
```

```
                MoveJ fixfix_pos{9}, vmax, z50, tool0;
            MoveJ reine_pos{12}, vmax, z50, tool0; !Kontakternas
position
        ELSEIF answer = 2 THEN
            WaitRob \ZeroSpeed;
        ENDIF
    ENDPROC
ENDMODULE
```